Al-Tamimi J. Spectral tilt as an acoustic correlate to pharyngealisation in Jordanian and Moroccan Arabic. *In: 18th International Congress of Phonetic Sciences (ICPhS)*. 2015, Glasgow, UK.

SPECTRAL TILT AS AN ACOUSTIC CORRELATE TO PHARYNGEALISATION IN JORDANIAN AND MOROCCAN ARABIC

Jalal Al-Tamimi

Newcastle University
jalal.al-tamimi@newcastle.ac.uk

ABSTRACT

The aim of this study is to evaluate the role of spectral tilt, alongside the traditionally looked at frequencies of the first two formants, in describing the acoustic characteristics of pharyngealisation in Jordanian and Moroccan Arabic. Twenty male speakers (10 per dialect) produced vowels in each dialect preceded by /d dˤ/. Normalised spectral tilt results show an overall lowered values for voice quality correlates, e.g., $*H_1$-$*H_2$, $*H_1$-$*A_1$, $*H_1$-$*A_2$, $*H_1$-$*A_3$, and [$-$ATR] correlate $*A_1$-$*A_2$, and an overall raised values for $*A_1$-$*A_3$ and $*A_2$-$*A_3$ in the pharyngealised context. Results for the former group suggest a tense voice caused by the larynx being raised [24, 26, 28, 35], whereas in the latter suggest a higher energy component close to the F2-F3 region [16]. High classification rates were obtained and showed that spectral tilt was able to distinguish pharyngealised vs non-pharyngealised well, advocating its importance as an acoustic cue for pharyngealisation in Arabic.

Keywords: Pharyngealisation, Spectral tilt, RTR/ATR/CET, Jordanian and Moroccan Arabic

1. INTRODUCTION

Pharyngealisation is a secondary articulation that involves a retraction of the body and root of the tongue towards the pharyngeal wall [28]. This secondary articulation is in general located near the tip of the epiglottis, and is accompanied by a raised larynx; the net result of these two articulations is that the entire pharynx is constricted [25]. In Arabic, pharyngealisation is associated with dental/alveolar consonants, though it extends to other places of articulation [19, 29]. Using articulatory data, researchers have shown that the constriction is located either towards the posterior pharynx wall near the uvula [14, 38] or with the epiglottis forming a constriction with the pharyngeal wall, which causes the tongue root to retract and the larynx to raise [2, 27]. This has led researchers to posit various articulatory correlates to account for the production of these consonants, e.g. velarisation, uvularisation, or pharyngealisation [2, 14, 27, 38, 39]. In Arabic these are referred to as "emphatics" and they have been described as involving a slight retraction of the tongue dorsum (i.e., velarisation), that is accompanied by pharyngeal constriction (i.e., pharyngealisation), slight lip rounding/protrusion (i.e., labialisation) and/or increased tension of the entire oral and pharyngeal musculature showing these consonants as more fortis than the plain segments [29]. This leaves open the question of the exact articulatory and thus acoustic correlates of emphasis/pharyngealisation in Arabic.

From an acoustic point of view, nearly all the studies have looked at formant frequencies in the vowels surrounding pharyngealised consonants and the results suggest a lowered F2 is the main acoustic correlate [1–4, 7, 14, 21, 23, 27, 32, 33, 38, 39], followed by a raised F1 as a secondary acoustic correlate, [2–4, 7, 14, 21, 23, 27, 33]. The frequency of F3 was also shown to differ in pharyngealised contexts due to the slight lip-rounding/protrusion and/or sulcalisation of the tongue body, with high F3 frequencies observed for back vowels e.g., /u:/ and low F3 for front, e.g., /i:/, although this was reported in very few studies, e.g., [2, 4, 21]. This has shifted the attention of researchers from the other acoustic cues that play a role in distinguishing pharyngealised vs non-pharyngealised consonants.

Indeed, the various accounts summarised above suggest that the articulatory correlates of pharyngealisation in Arabic form a complex picture with retraction of part(s) of the tongue (dorsum and/or root) and of the epiglottis, narrowing of the pharyngeal wall, raising of the larynx, more tense/fortis articulation, and lip rounding/protrusion. However, the various acoustic accounts restrict themselves to analysing, at best, the surrounding vowels' first two formants. To the best of my knowledge, there does not seem to be any accounts of the acoustic correlates of the tense/fortis articulation, and/or of raised larynx in describing pharyngealisation (but see [5]).

This can be explained by the fact that many of the formal accounts of pharyngealisation/emphasis subscribe to the "Articulator Theory" [17] for which distinctive features should have their basis in articulation [34]. [+RTR] ("Retracted Tongue Root") is currently the most used distinctive feature to account for pharyngealisation, and acoustic accounts suggest that its primary acoustic correlate is the lower F2 frequency [34, 37]. Indeed, [33] suggest that emphasis spread actually consists of backing of the tongue dorsum with uvularisation as an articulatory correlate and only a lowered F2 as an acoustic, whereas pharyngealisation entails a retraction of the tongue root as an articulatory correlate with a lowered F2 as the main acoustic correlate and a raised F1 as a secondary one and is assigned a [−ATR] feature. This suggests that, in formal representation, the two features [−ATR] and [+RTR] are equal in representing effects of pharyngealisation (but see [36]). If this is the case, then the acoustic correlates of pharyngealisation are lacking in detail. The literature on [±ATR] vowel harmony shows that [−ATR] vowels have a raised F1 as the main acoustic correlate followed by a lowered F2 and F3, high energy above F1 leading to a flatter spectral tilt (through the *A*1-*A*2 metric), and tense/creaky voice as secondary features [6, 13, 15, 22]. The acoustic correlates of "Advanced Tongue Root" were initially described by [16] as an alternative to the feature [±tense] [20] and [±covered] [11] to account for the distinction between tense *vs* lax vowels in English and for vowel harmony in West African languages. Retracting the tongue root (as opposed to advancing it) has two acoustic consequences: i) it raises the frequency of F1, which increases the energy above F1 and around F2-F3 and ii) it lowers the frequency of F2 [16].

Due to the mismatch between the articulatory and the acoustic correlates of pharyngealisation, the aim of this paper is to evaluate the role of spectral tilt in distinguishing pharyngealised *vs* non-pharyngealised environments. Tense articulation and raised larynx leads to a lowered/flatter spectral tilt [24, 26, 28, 35] and to an increase in the energy in high frequencies [16]. A complete comparison of all acoustic cues used in the description of [−ATR] vowels is presented elsewhere, and include formant frequencies and bandwidths (F1 to F3) at onset and mid-point, intensity and *f*0 (see [5] for more detail).

2. METHODOLOGY

2.1. Speakers and data recording

Twenty Jordanian and Moroccan male speakers (10 of each dialect), aged 20 to 30, with no history of speech and/or language disorder were asked to produce a word list in ˈC_1V_1C, ˈC_1V_1CV, ˈC_1V_1CVC or CVˈC_1V_1C syllable structures, where C_1 = /d or dˤ/ and V_1 = /iː ɪ eː ɐ aː oː ʊ uː/ in Jordanian Arabic or /iː ə aː ʊ uː/ in Moroccan Arabic [4]. The words were randomly presented with five repetitions in an adapted carrier sentence (using Modern Standard Arabic script without vocalisation). Speakers were asked to produce each word without the carrier sentence at normal rate and unmarked style. Recordings were directly made on a PC in a sound attenuated room, with a sampling frequency of 22 kHz, 16 bits quantisation, in mono channel and a Sony MS 907 microphone (distance 30 cm from the speakers' mouths). The total number of words produced by the speakers was 700 for Jordanian and 500 for Moroccan Arabic (henceforth JA and MA); the productions of the vowel /oː/ in /d or dˤ/ in JA were excluded.

2.2. Acoustic analyses

The data were segmented manually and acoustic measurements were performed using Praat [10]. Formants and *f*0 were estimated prior to computing spectral tilt measures. Formant frequencies (F1, F2 and F3) of the vowels following /d and dˤ/ were automatically obtained using Praat's default "Burg" algorithm, with a 25 ms Gaussian window, a 5 ms time step and interpolation; five formants were estimated with a maximum frequency of 5 kHz. Fundamental frequency was estimated using the autocorrelation method with a 5 ms time step and an effective Gaussian window length of 30 ms with a pitch ceiling and floor adapted to each speaker (ranging between 100-300 Hz). The sound files were low-pass filtered with an anti-aliasing filter which had a cut-off frequency of 5 kHz, down-sampled to 10 kHz, and pre-emphasized by a factor of 0.98. Intervals 40 ms long were defined, right-aligned at the onset of the following vowel, and windowed using a Kaiser-2 window function. A DFT was computed from each windowed interval and the logarithmic power spectral density, with a bin size of 11 Hz, was computed. The amplitudes of the first and second harmonics and of the first to third formants were automatically obtained by detecting the highest peaks for a particular harmonic (see [5] for more detail). The automatic detections of formant frequencies, and highest peaks were manually checked to prevent errors. Following this, normalised $*H_1$, $*H_2$, $*A_1$, $*A_2$ and $*A_3$ were obtained following [18] to correct for the boosting effect of formants on these harmonics. Then amplitude differences were obtained for $*H_1$-$*H_2$, $*H_1$-$*A_1$, $*H_1$-$*A_2$, $*H_1$-$*A_3$, $*A_1$-$*A_2$, $*A_1$-$*A_3$ and $*A_2$-$*A_3$ to evaluate voice quality and the high energy components associated with the pharyngealised context.

2.3. Statistical analyses

Acoustic measurements were submitted to multiple two-way Linear Mixed Effects Models (LMM) using SPSS 22, with each acoustic measurement (amplitude differences) as dependent variables; vowel (seven levels for JA and five for MA) * consonant (two levels) formed the two-way interaction and speaker was treated as a random factor (intercept) with vowel*consonant as random slopes, following the maximal specification model to account for individual variations in the realisation of each vowel and consonant [8, 9]. Following each LMM, the "Best linear unbiased predictors" (BLUPs) taking the fixed and random factors into account are used to evaluate how robust spectral tilt results are in separating pharyngealised from non-pharyngealised consonants. To do that, Linear Discriminant Function Analysis was applied, with the *leave-one-out* method for cross-validation, consonant as a grouping variable and the BLUPs as predictors.

3. RESULTS

For the formants, the results are in accordance with those reported above, in both dialects, pharyngealised environments showed a raised F1 (for all but /ɐ a:/ in JA), a lowered F2 and a raised F3 for /u:/ in the following vowel (see [5] for more details). In the sections below, we will highlight significant differences in spectral tilt results.

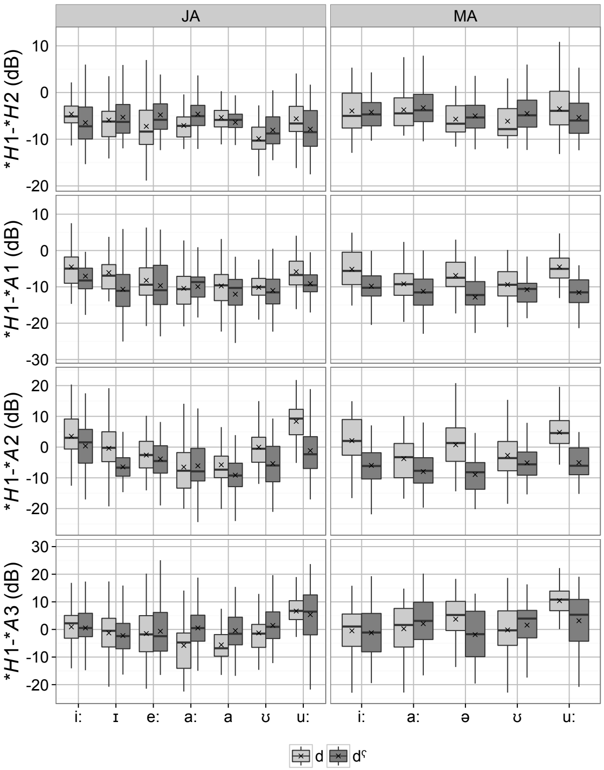
3.1. *H_1-*H_2

Fig. 1 presents results for the pharyngealised vs non-pharyngealised contexts. In JA, they show significantly higher values of *H_1-*H_2 for /e: a: ʊ/ (but low for /i: u:/ in the pharyngealised context, $p<0.01$), while in MA, *H_1-*H_2 values are significantly higher for /ʊ/ and lower for /u:/ ($p<0.01$). The overall low values reflect a shallower spectral tilt and thus tense articulation [24, 26, 28, 35].

3.2. *H_1-*A_1

H_1-A_1 values presented in Fig. 1 were significantly lower in /i: ɪ ɐ u:/ in JA ($p<0.01$), while all vowels in MA showed significantly lower *H_1-*A_1 in the pharyngealised context ($p<0.01$). Again, these low values seem to reflect the lower spectral tilt associated with tense articulation [24, 26, 28, 35].

Figure 1: Spectral tilt results for *H_1-*H_2, *H_1-*A_1, *H_1-*A_2, and *H_1-*A_3, in JA and MA



3.3. *H_1-*A_2

Results of *H_1-*A_2 (see Fig. 1) follow the same pattern with overall lower values for all JA vowels (but /e: a:/) and for all MA vowels in the pharyngealised context ($p<0.01$). These results seem to confirm the low spectral tilt that is due to tense articulations [24, 26, 28, 35].

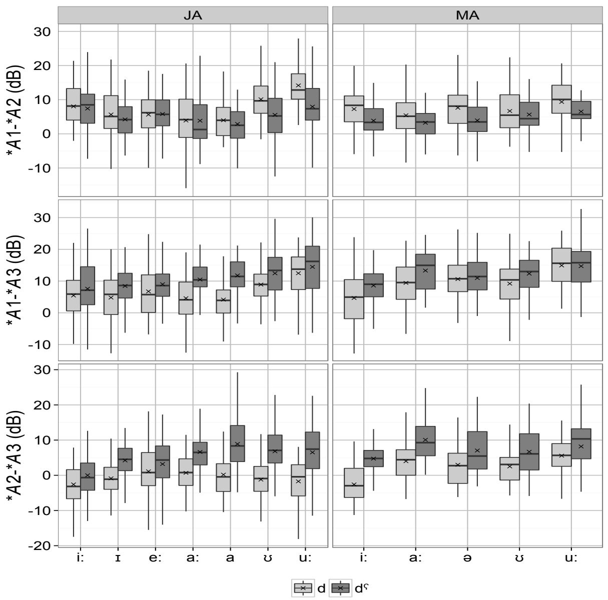
3.4. *H_1-*A_3

H_1-A_3 results presented in Fig. 1 suggest that /a: ɐ ʊ/ are the only vowels in JA to have higher values in the pharyngealized context ($p<0.01$), whereas in MA, lower values are observed for /ə u:/ ($p<0.01$). This again seem to be correlated with the tense articulation, though to variable degrees [24, 26, 28, 35].

3.5. *A_1-*A_2

A_1-A_2 results presented in Fig. 2 show an overall lower values in all JA vowels (but /i: e: a:/) and MA vowels in the pharyngealised context ($p<0.01$). This seems to follow the trends observed by [6, 13, 15, 22] for [−ATR] vowels to show flatter spectral tilt.

Figure 2: Spectral tilt results for $*A_1$-$*A_2$, $*A_1$-$*A_3$, and $*A_2$-$*A_3$, in JA and MA



3.6. $*A_1$-$*A_3$

$*A_1$-$*A_3$ results shown in Fig. 2 suggest that all the vowels in both JA and MA (but /ə u:/) have significantly high level of energy in the high frequencies in the pharyngealised context (p<0.01). This is compatible with the predictions from [16] that [−ATR] vowels will show more energy above F1.

3.7. $*A_2$-$*A_3$

And finally, results of $*A_2$-$*A_3$ presented in Fig. 2 show that for both JA and MA, all vowels in the pharyngealized context show significantly high level of energy in the high frequencies that is predicted for [−ATR] vowels, (p<0.01), [16].

3.8. Discriminant Analyses

Discriminant Analysis results seem to show relatively high classification rates with an overall 81% in JA and 86% in MA. In JA, $*A_2$-$*A_3$ is the highest predictor, having a classification rate of 80%; in MA, $*H_1$-$*A_1$, $*H_1$-$*A_2$, $*A_1$-$*A_2$, and $*A_2$-$*A_3$ were the highest predictors with 70%, 74%, 69%, and 71% respectively. These results confirm the important role of spectral tilt as an acoustic correlate to pharyngealisation in Arabic.

4. CONCLUSION AND DISCUSSION

The aim of this paper was to evaluate the extent to which spectral tilt is useful in characterising pharyngealisation in JA and MA. The results suggest an overall low spectral tilt indicating a flatter spectrum for $*H_1$-$*H_2$, $*H_1$-$*A_1$, $*H_1$-$*A_2$, $*H_1$-$*A_3$, $*A_1$-$*A_2$ and high spectral tilt values for $*A_1$-$*A_3$ and $*A_2$-$*A_3$. These results suggest tense articulation and a raised larynx position as predicted by the previous literature [24,26,28,35] and an increased level of energy in the high frequencies [16], both of which seem to be acoustic correlates of [−ATR] vowels [6,13,15,22]. These novel results suggest that spectral tilt is an acoustic correlate to pharyngealisation, and that this secondary articulation in Arabic is not *only* signalled acoustically by a lowered F2 and potentially a raised F1, as is the case in the majority of studies summarised above. Although some of the literature seem to equate the features [−ATR] and [+RTR], these two seem to be different as the former involves retraction of the tongue root, while the latter involves a constriction of the whole pharynx of which retracting the tongue root is just one component [30, 36]. The acoustic consequences of pharyngealisation reported here (and in [5]) suggest that the entire pharynx is constricted, leading to a tense articulation, a raised larynx and a retracted tongue root that causes lowering of the whole tongue. The feature [+RTR] thus needs to be redefined to account for these acoustic consequences, and either be replaced by the traditional [+pharyngeal] feature [30] (although this requires a raised F1 for all vowels) or by the feature [+cet] ("Constricted Epilaryngeal Tube") [31] following the "Laryngeal Articulator Model" [12]. [+cet] would represent the entire set of articulations – larynx raising, retraction of the tongue, tense articulation, and vowel centralisation – as a single unit. The results reported here (and in [5]) seem to show the acoustic correlates of [+cet] as being used in describing pharyngealisation in Arabic.

5. REFERENCES

[1] Al-Ani, S. 1970. *Arabic Phonology : an Acoustical and Physiological Investigation*. Paris: The Hague Mouton.

[2] Al-Tamimi, F., Heselwood, B. 2011. Nasoendoscopic, videofluoroscopic and acoustic study of plain and emphatic coronals in Jordanian Arabic. In: Heselwood, B., Hassan, Z., (eds), *Instrumental studies in Arabic phonetics*. John Benjamins 165–191.

[3] Al-Tamimi, J., Barkat-Defradas, M. 2003. Inter-dialectal and inter-individual variability in production and perception: a preliminary study in

Jordanian and Moroccan Arabic. Ferrando, I., Sanchez Sandoval, J. J., (eds), *Proc. 5th AIDA, Cádiz, Spain* 171–186.

[4] Al-Tamimi, J., 2007. Static and Dynamic cues in vowel production: a cross dialectal study in Jordanian and Moroccan Arabic. *Proc. 16th ICPhS, Saarbrücken* 541–544.

[5] Al-Tamimi, J., submitted. Revisiting acoustic cues of Pharyngealization in Jordanian and Moroccan Arabic.

[6] Aralova, N., Grawunder, S., Winter, B. 2011. The Acoustic Correlates of Tongue Root Vowel Harmony in Even (Tungusic). *Proc. 17th ICPhS, Hong Kong,* Hong Kong. 240 – 243.

[7] Barkat-Defradas, M., Al-Tamimi, J., Benkirane, T. 2003. Phonetic variation in production and perception of speech: a comparative study of two Arabic dialects. *Proc. 15th ICPhS, Barcelona* 857–860.

[8] Barr, D. J. 2013. Random effects structure for testing interactions in linear mixed-effects models. *Quant. Psych. & Meas.* 4, 1–2.

[9] Barr, D. J., Levy, R., Scheepers, C., Tily, H. J. 2013. Random effects structure for confirmatory hypothesis testing: Keep it maximal. *J. Mem. & Lang.* 68(3), 255–278.

[10] Boersma, P., Weenink, D. 2014. Praat. doing phonetics by computer. v. 5.3.63: Retrieved 24 january 2014 from http://www.praat.org/.

[11] Chomsky, N., Halle, M. 1968. *The sound pattern of English*. New York: Harper & Row.

[12] Esling, J. H. 2005. There Are No Back Vowels: The Laryngeal Articulator Model. *The Canadian Journal of Linguistics* 50(1), 13–44.

[13] Fulop, S., Kari, E., Ladefoged, P. 1998. An Acoustic Study of the Tongue Root Contrast in Degema Vowels. *Phonetica* 55(1-2), 80–98.

[14] Ghazeli, s. 1977. *Back Consonants and Backing Coarticulation in Arabic*. Ph. d. dissertation.

[15] Guion, S. G., Post, M. W., Payne, D. L. 2004. Phonetic correlates of tongue root vowel contrasts in Maa. *J. Phon.* 32(4), 517 – 542.

[16] Halle, M., Stevens, K. 1969. On the Feature 'Advanced Tongue Root'. *Quart. Prog. Rep. No. 94, M.I.T.* 209–215.

[17] Halle, M., Vaux, B., Wolfe, A. 2000. On feature spreading and the representation of place of articulation. *Ling. Inq.* 31(3), 387–444.

[18] Iseli, M., Shue, Y.-L., Alwan, A. 2007. Age, sex, and vowel dependencies of acoustic measures related to the voice source. *JASA* 121(4), 2283–2295.

[19] Jakobson, R. 1957/1962. Mufaxxama - The 'emphatic' phonemes in Arabic. In: *Jakobson, R. (Ed.): Selected Writings I: Phonological Studies (originally published in 1957 in E.Pulgram (Ed.): Studies presented to Joshua Whatmough)*. The Hague: Mouton 510–522.

[20] Jakobson, R., Fant, G., Halle, M. 1952/1976. *Preliminaries to Speech Analysis: The distinctive features and their correlates*. MIT Press.

[21] Jongman, A., Herd, W., Al-Masri, M., Sereno, J., Combest, S. 2011. Acoustics and perception of emphasis in Urban Jordanian Arabic. *J. Phon.* 39(1), 85–95.

[22] Kang, H., Ko, S. 2012. In search of the acoustic correlates of tongue root retraction in three Altaic languages: Western Buriat, Tsongol Buriat, and Ewen. *Altai hakpo* 22, 179–203.

[23] Khattab, G., Al-Tamimi, F., Heselwood, B. 2006. Acoustic and auditory differences in the /t/-/ṭ/ opposition in male and female speakers of Jordanian Arabic. *Perspectives on Arabic Linguistics XVI* volume 266. John Benjamins 131–160.

[24] Klatt, D., Klatt, L. 1990. Analysis, synthesis and perception of voice quality variations among male and female talkers. *JASA* 87, 820–856.

[25] Ladefoged, P., Maddieson, I. 1996. *The sounds of the world's languages*. Cambridge, MA: Blackwell.

[26] Lasarcyk, E. 2007. Investigating larynx height with an articulatory speech synthesizer. *Proc. 16th ICPhS, Saarbrücken* 2213–2216.

[27] Laufer, A., Baer, T. 1988. The emphatic and pharyngeal sounds in Hebrew and in Arabic. *Lang. & Speech* 31, 181–205.

[28] Laver, J. 1994. *Principles of Phonetics*. Cambridge University Press.

[29] Lehn, W. 1963. Emphasis in Cairo Arabic. *Language* 39(1), 29–39.

[30] McCarthy, J. J. 1994. The phonetics and phonology of Semitic pharyngeals. In: Keating, P., (ed), *Phonological Structure and Phonetic Form: Papers in Laboratory Phonology III*. Cambridge University Press 191–233.

[31] Moisik, S., Esling, J. H. 2011. The 'whole larynx' approach to laryngeal features. *Proc. 17th ICPhS, Hong Kong* 1406–1409.

[32] Obrecht, D. H. 1968. *Effects of the second formant on the perception of velarisation consonants in Arabic*. The Hague: Mouton.

[33] Shahin, K. N. 1997. Acoustics of pharyngealization vs. uvularization harmony. In: *Perspectives on Arabic Linguistics X*. John Benjamins 215–237.

[34] Shahin, K. N. 2011. Phayngeals. In: van Oostendorp, M., Ewen, C. J., Hume, E., Rice, K., (eds), *The Blackwell Companion to Phonology*. Blackwell Publishing chapter 25, 604–627.

[35] Sundberg, J., Askenfelt, A. 1981. Larynx height and voice source. a relationship? *Quart. Prog. & Stat. Rep., 22(2-3)* 23–36.

[36] Vaux, B. 1999. A Note on Pharyngeal Features. Kuno, S., Bert Vaux, e., (eds), *Harvard Working Papers in Linguistics 7* 39–63.

[37] Watson, J. C. E. 2007. *The Phonology and Morphology of Arabic*. OUP Oxford.

[38] Zawaydeh, B., de Jong, K. 2011. The phonetics of localising uvularization in Arabic. In: Heselwood, B., Hassan, Z., (eds), *Instrumental studies in Arabic phonetics*. John Benjamins 257–276.

[39] Zeroual, C., Esling, J. H., Hoole, P. 2011. EMA, endoscopic, ultrasound and acoustic study of two secondary articulations in Moroccan Arabic. In: Heselwood, B., Hassan, Z., (eds), *Instrumental studies in Arabic phonetics*. John Benjamins 277–297.